An Optical Millimeter Wave Generation using Carrier Suppression Modulation Scheme based on Frequency 12- tupling LiNbO3 MZM without an Optical Filter

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Abstract

This article presents a novel method for the generation of optical millimeter wave (mmw) from a microwave signal using a single Lithium Niobate Mach Zehnder Modulator (LiNbO3 MZM). The carrier suppression scheme supports the experimental setup for achieving 12-tupling frequency by suppressing the sidebands of wave signal by fixing the modulation and bias voltage as 10V. The absence of optical filter leads to fast tuning of required frequency which helps to achieve 12 tupling frequency effectively. The pseudo random bit sequence in the rate of 100 Gbps is transmitted through a single mode optical fiber for a distance of 60 km. The experiment achieves a larger data rate, less complexity and better performance in the absence of an optical filter when compared to other conventional methods. The proposed method performs error free transmission along the fiber of length 60 km and the efficiency of the generated mmw is analyzed by using optical spectrum, RF spectrum and eye diagram visualizers. The quality factor is also included in the paper using Bit Error Rate (BER) analyzer to prove that the energy loss is negligible in the setup. The BER performance of the generated mmw for different length of the fiber is also presented.

Keywords: Frequency 12-tupling, Lithium Niobate Mach-Zehnder modulator, Millimeter wave generation Radio over Fiber; Optical carrier suppression, Optical Spectrum.

I. Introduction

Nowadays the need for huge bandwidth is observed in the wireless and wired communication for applications like high definition (HD) video conferencing and for large content multimedia services [1]. The use of microwave range for the large data transmission leads to congestion problem which increases the time delay in microwave range [2]. In this scenario the use of mmw plays an important role to overcome the drawbacks of microwave range due the availability of wide bandwidth [3]. By the use of mmw range high speed data transmission is possible without any propagation loss and due to the presence of large bandwidth more amount of data can be transmitted without congestion [4, 5]. The use of mmw achieves better data rate so that the time delay is less when compared to the microwave range signal [6]. The microwave signal is not supported for long distance transmission due to low sampling rate and it also contributes to fading effect [7]. The widely used medium for the transmission of mmw is an optical fiber rather than a coaxial cable due to its ability to avoid interference and cross talk [8, 9]. Among the frequency range of waves, the mmw range seems to be suitable for high speed data transfer due to the availability of large bandwidth, security and efficiency [10]. The transmission of mmw through an optical fiber has the advantages like reduced dispersion and fading effect, also it is possible to develop a low cost circuit with better performance [11, 12]. The major application of mmw includes uses of radar sensor in the medical field and in highly secured places like defence to provide high quality data transmission [13]. In RoF communication the data transmission in mmw range can be achieved at the rate of Giga bit per second (Gbps) which will reduce the effects like lagging and broadening of wave signal in long distance transmission [14,15]. The availability of wide bandwidth in the mmw range can carry large amount of information and thus motivates the researchers to devise methods for the generation of mmw in the field of optical communication [16, 17]. In this article an optical mmw is generated using LiNbO3 MZM modulator based on frequency 12-tupling without an amplifier and filter. The carrier suppression method used in this setup inorder to suppress undesired sideband signal and to generate a robust mmw signal in the base station. The use of optical filter to prevent the undesired sidebands from the desired signal is not required due to the negligible side bands produced by the proposed method. Hence the complexity and the cost of the proposed experimental set up gets reduced due to the absence of optical filter. In the most of the methods discussed in the literature for the generation of mmw more than one optical filters is employed to reduce the undesired signal which in turn increases the product cost [18, 19]. The data transmission at the rate of 100 Gbps is performed for a 60 km distance through a single mode optical fiber by applying a modulation voltage and bias voltage of 10 V in the MZM to reduce the widening of the wave signals so that dispersion effect is reduced.

II. Principle Of Millimeter Wave Generation

The experimental setup for the generation of optical mmw based on frequency 12-tupling is shown in figure 1. The continuous wave (CW) laser acts as a message signal in the central station with the pseudo random bit sequence (data) at the rate of 100 Gbps and signal generator acts as a carrier of the message signal. The carrier signal with data in microwave range is transmitted into the LiNbO3 MZM for generating mmw and achieves a long distance transmission through an optical fiber. The modulation and bias voltage are set as 10 V for performing carrier suppression in which the undesired even order optical side bands are suppressed so as to produce a frequency 12- tupling mmw signal.

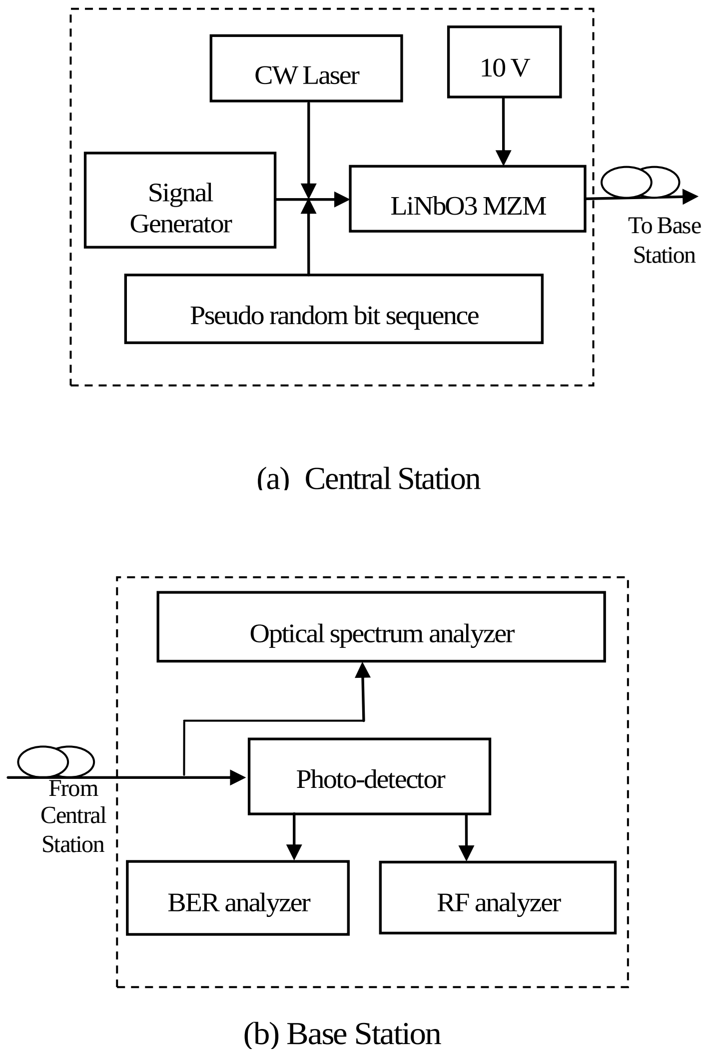


Fig. 1. Experimental setup for mmw generation based on frequency 12-tupling.

The carrier suppressed mmw is allowed to pass through a single mode optical fiber for 60 km distance without using an amplifier. The carrier suppression method has the ability to strengthen the mmw signal to achieve long distance transmission so that the use of amplifier can be removed. In the base station an optical fiber is connected to an optical spectrum analyzer before entering the signal into photo detector to check whether the generated optical mmw is robust to fading effects. The photo-detector in the base station will convert the optical signal into an electrical signal then the output is given to the visualizers like RF spectrum and BER analyzer to verify the quality of generated signal.

A. Single Mode Optical Fiber

In the experimental setup for the transmission of modulated mmw, a single mode optical fiber is used to reduce the fading effect that occurs during long distance transmission. The figure 2 shows the polarization graph to identify the strength of mmw as a carrier along the fiber for a distance of 60 km.

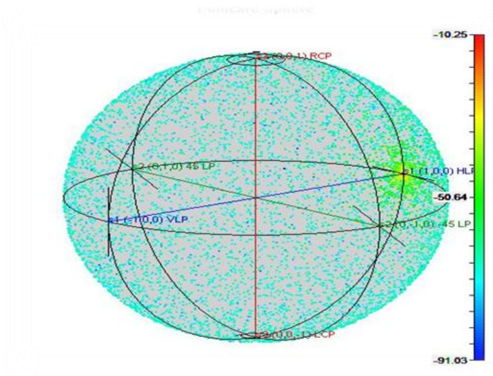


Fig. 2. Polarization of the mmw through a single mode fiber

The axis line of the polarization globe in the Fig. 2 clearly shows that generated mmw has the required strength to transmit data for a distance of 60 km with negligible propagation loss and phase noise. The power loss -10.25 dB occurred during the transmission is negligible; the axis of the globe maintains its wavelength which supports the mmw transmission in the single mode fiber. The acceptance angle of the optical fiber is more in the perpendicular polarized light signal which helps to achieve better transmission and with minimum fading effect.

B. Mathematical analysis:

In this section the mmw generated using carrier suppression technique based on frequency 12-tupling is mathematically analyzed. The data rate of 100 Gbps is given to the MZM with the carrier signal of frequency ω_c by fixing the bias voltage and modulation voltage to 10 V for suppressing the unwanted even order optical sideband. The modulated signal has the carrier frequency $(\omega_o - \omega_c)$ and $(\omega_o + \omega_c)$, where the laser frequency is considered as $(\omega_o - \omega_c)$.

The modulator electric field applied is expressed as

$$E_{in}(t) = E_0 \cos(\omega_0 t)$$

Where E_0 is the electric field amplitude and the voltage of the millimeter wave signal is given as

$$V_1(t) = V_e \cos(\omega_c t + \varphi_1)$$

while V_e and φ_1 are amplitude and phase of electrical signal respectively.

After the suppression of all the even order optical sidebands, the output of the LiNbO3 modulator is expressed using the equation given below

$$E_{out}(t) \;\; = \; E_0 \cos(\omega_o t) \left(\pi/_2 + \; \beta_1 \cos(\omega_c t \; + \; \varphi_1)\right])$$

$$\approx B_1(\beta_1) E_0 \mathrm{Cos}\,((\omega_o - \; \omega_c)t - \varphi_1) + \cos((\,\omega_o + \; \omega_c)t + \varphi_1)$$

B_1 is the first order Bessel function of the first kind, β_1 is the phase modulation index

At the output of photodiode, an electrical signal which is 12 times the frequency of the driving signal is produced. The generated signal can be written as,

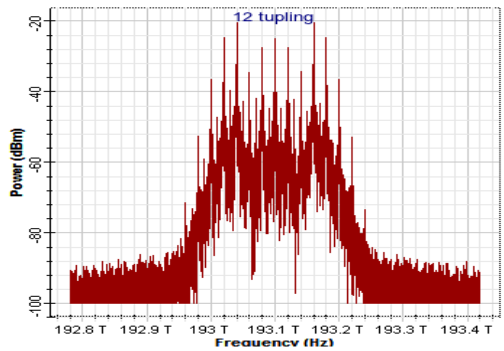
$$V_{out}(t) = \; B_1^2(\beta_1)\, B_1^2((\beta_2)\;\; E_0^2 \cos(12\omega_c t + 8\varphi_1 + 8\varphi_2)$$

The expression of $V_{out}(t)$ indicates that a frequency 12- tupling is produced in the mmw range by the proposed experimental setup and the generated mmw is observed in both optical and electrical domain. The error free transmission and signal quality is verified by using eye diagram and Q – factor visualizers after transmitting the optical signal for a 60 km distance.

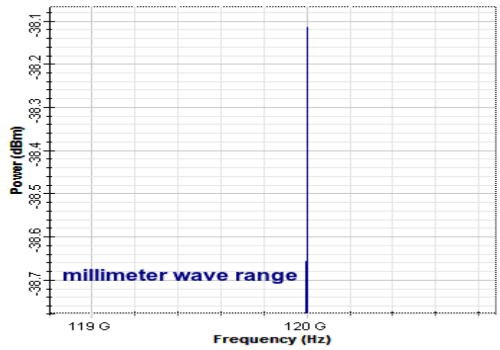
III. Experimental Results

The microwave range 10 GHz with the message signal having a data rate of 100 Gbps is given as the input of LiNbO3 MZM modulator and generation of 120 GHz mmw signal is achieved without any propagation loss. The frequency is increased by 12 times by using the carrier suppression technique and thus the output of the modulator falls in mmw range. The conversion of frequency can be clearly observed in the optical and RF spectrum analyzer. The quality of the signal is verified using the visualizers and the loss occurred during signal transmission through an optical fiber for a distance of 60 km is evaluated using Q-factor originated from the BER analyzer.

The optical spectrum and the electrical spectrum of the mmw signal for the frequency 120 GHz at a distance of 60 km is shown in figure 3 (a, b). By observing the graphs figure 3 (a) it is clear that the carrier suppression is performed to produce mmw by suppressing unwanted even order side bands and the difference between the two projected bands give a 12 tupling frequency. The electrical spectrum shown in figure 3 (b) is produced by using electrical spectrum analyzer connected after photo detector and a 12 times the frequency (120 GHz) is observed clearly in the power versus frequency graph.



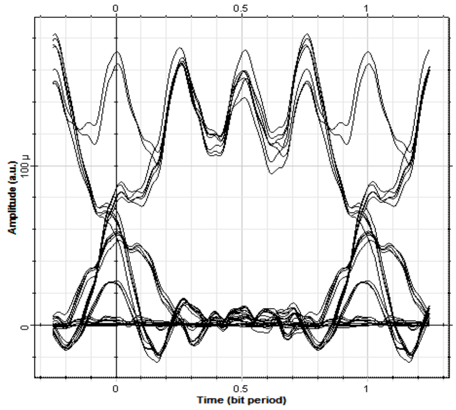
(a) Optical spectrum



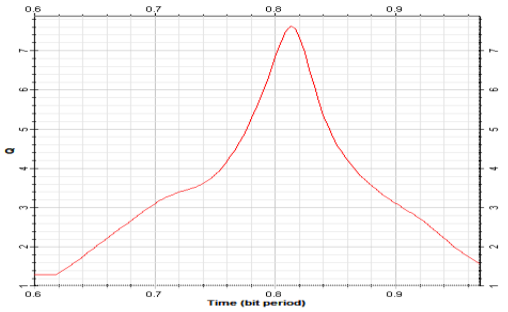
(b) Electrical spectrum

Fig. 3. Spectrum of the generated mmw signal.

The wide opening of the eye pattern in the eye diagram shown in figure 4 (a) clearly indicates the error free transmission is achieved through a 60 km optical fiber and can be reconstructed in the base station without any data loss. The Q-factor shown in figure 4 (b) is obtained by using BER analyzer indicates the energy loss occurred during the transmission of mmw from an optical fiber is negligible. The curve at the peak of the graph of Q- factor shows the quality of the signal received in the base station. In case of any propagation loss in during the data transmission through an optical fiber it can be clearly seen that by using the Q-factor graph as the peak point of the graph will be sharp and discontinuous. The propagation loss is due to the physical damage in the optical fiber and the reduction of signal power during transmission. In this experimental setup the external modulator has the capacity to create strong mmw signal by providing proper bias and modulation voltage of 10 V to travel through the 60 km long distance fiber with a negligible data loss.



(a) Eye diagram



(b) Q- Factor

Fig. 4. Observed results after the transmission of the generated optical mmw signal over 60 km.

The carrier suppression waveform of the generated 120 GHz mmw signal is shown in figure 5 and it indicates that the unwanted side bands are suppressed to achieve frequency 12 tupling. The waves with high amplitude are desired signal for long distance transmission along the fiber without any time delay. In the experimental set up the photo detector is followed by a oscilloscope visualizer to display the suppressed waveform in the electrical domain.

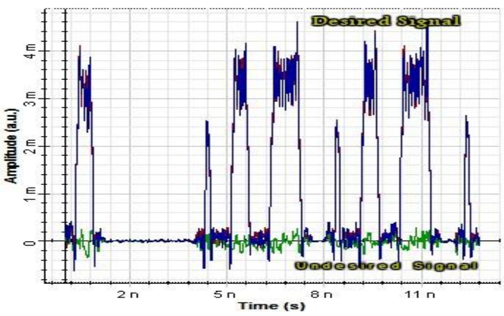
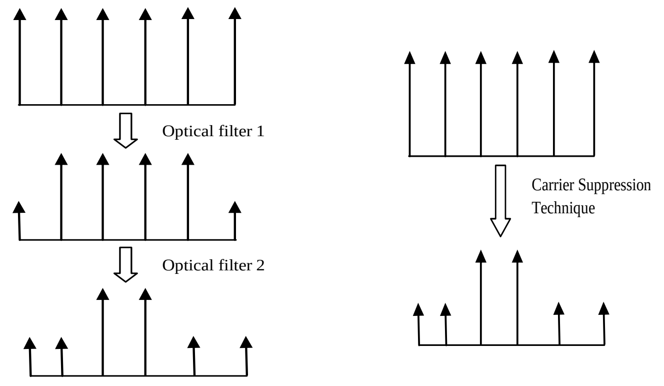


Fig. 5. Carrier suppression waveform for a distance of 60 km.

By observing the figure 5 it is inferred that the signal passing through the optical fiber for a distance of 60 km from central station to base station has better quality so as to reconstruct the data from the waveform.



(a) Using Optical filter

(b) Using Carrier Suppression

Fig. 6. Difference of using optical filter and carrier suppression technique

The advantage of using carrier suppression technique helps to eliminate the use of an optical filter which is evident in figure 6. The figure 6 (a) shows the ordinary side band suppression using optical filter and the figure 6 (b) shows the carrier suppression technique for the side band suppression used in this paper. The function of both optical filter and the carrier suppression techniques are the same, both are used to suppress undesired side bands. In the figure 6 (a) at the top of the figure is considered as the six sidebands. The method [18] uses an optical filter 1 both the side bands are suppressed and by using another optical filter 2 the next two side bands are suppressed and the suppressed side bands are the undesired side bands. The two side bands without suppression is considered as the desired signal which has the 12 tupling frequency. Even in [19] the aforementioned two steps are to be carried out by using two optical filters so that the complexity and cost of the circuit gets increased. In figure 6 (b) uses carrier suppression technique to suppress the undesired signal. By providing the exact modulation voltage, bias voltage and the extinction ratio in the modulator the simulation result depicts the usefulness of carrier suppression. The 12 tupling achieved by suppressing the carrier signal is a one step process. In both cases the desired signal is preserved but optical filter is required in figure 6 (a) and no optical filter is used in figure 6 (b). Thus the advantage of this paper is the absence of optical filter and thus the complexity and the cost of the experimental setup is reduced.

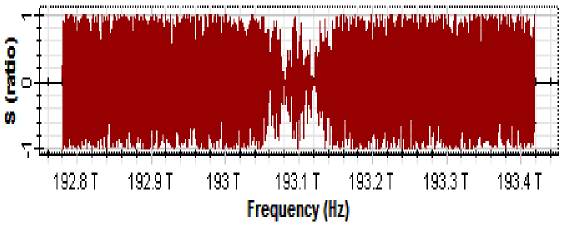
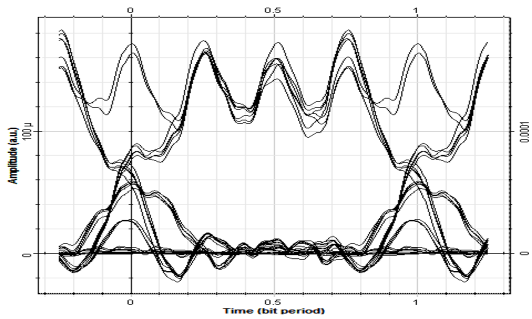


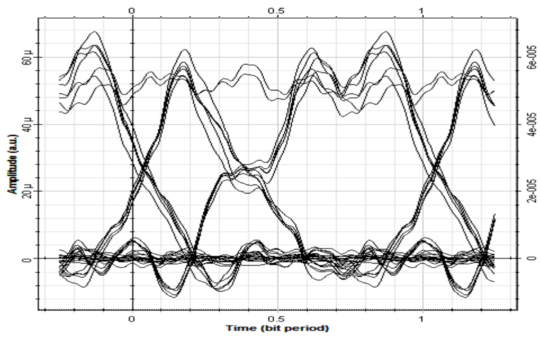
Fig. 7. Sampling of the mmw signal

When compared to the microwave range the mmw has more capacity to carry large information and the ability to travel for a long distance. The sampling of mmw signal shown in figure 7 determines the strength of the mmw signal. When the sampling of the wave increases, the power of the wave signal also gets increased.

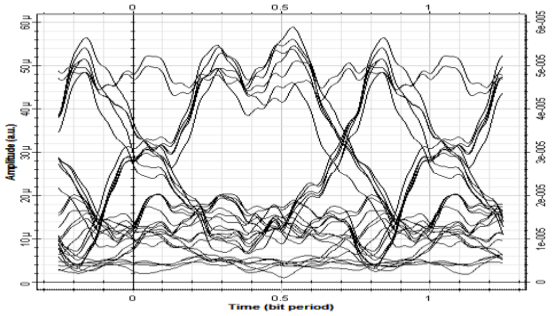
In figure 7 it is clear that the laser source of frequency 193.1 THz with a linewidth of 10 MHz is maintained to reach the base station without any dragging effect of the wave signal. The signal ratio is between -1 to +1 which indicates that the sampling of the mmw signal has better strength and supports long distance transmission without propagation loss. From the results it is evident that the experimental setup for the generation of 12 tupling mmw signal is robust. The cost effective method has less propagation loss and does not require a filter and amplifier.



(a) 60 km



(b) 65 km



(c) 70 km

Fig. 8. Eye Diagram pattern for different fiber length.

The transmission of mmw through an optical fiber is done for a distance of 60 km in the experimental work. An investigation is carried out with BER for different fiber length and it is understood that when BER is increased with fiber length, the wide opening of eye pattern is reduced. The figure 7 shows different eye pattern obtained after the transmission of mmw signal through a single mode optical fiber for a distance of 60 km . From the figure 8 (a), (b) and (c) it is evident that when fiber length increases the wide opening of eye pattern is an indication that the signal gets distorted during transmission.

IV. Fiber Length versus BER

The figure 9 shows a graphical representation to identify the variation occurred with different length of fiber used for the transmission of mmw based on 12 tupling for the experimental setup. In the figure, for a fiber length of 60 km the BER is maintained so that in the base station the data can be preserved and reconstructed. When the fiber length is increased to 65 km the fading effect is initiated and in the 70 km BER get drastically increased.

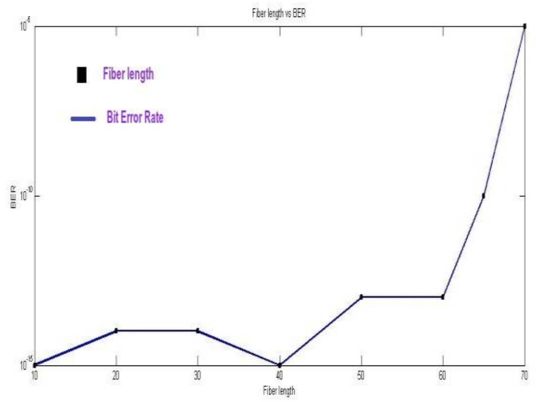


Fig. 9. Graphical representation of BER versus Fiber length.

Table 1. Fiber length vs BER

Fiber Length in km	BER
10	10^{-15}
20	10^{-12}
30	10^{-12}
40	10^{-15}
50	10^{-9}
60	10^{-9}
70	10^{-5}

The table 1 shows the BER value as a function of different fiber length ranging from 10 km to 60 km. When the fiber length increases to 70 km the BER value is increased, which in turn results in propagation loss. The simulation results shows that up to 65 km error free transmission can be achieved and further distance by using an amplifier in the base station the BER value can be reduced and thus the system can achieve better error free performance.

V. Extinction Ratio Vs Quality Factor

In the experimental setup the extinction ratio and the quality factor plays an important role for generating an error-free output signal in the base station. During the simulation an iterative process is carried out for obtaining a good quality signal at the output. The quality factor indicates the lower rate of energy loss during the transmission of signal through an optical fiber. When Q-factor increases or become constant, it indicates that no loss occurred in between center station and base station. The extinction ratio and the Q-factor has a bond for helping the transmission of data without errors. When extinction ratio is increasing with quality factor then the system can achieve better tupling frequency for carrying large amount of data. The table 2 shows simulation readings used to maintain better quality signal at the output of a 60 km fiber. From the table we can easily conclude that when the extinction ratio is less than 30 dB the system produces a better quality signal without any degradation in the Q-factor value. In the table when extinction ratio increases to 35 dB the Q-factor goes down which means that the threshold for maintaining good quality signal is reached and if exticition ratio further increase the Q-factor goes on decreasing due to increase in BER value.

Table 2. Extinction ratio vs Q-factor

Extinction ratio in dB	**Q- factor**
10	66.555
15	66.324
20	65.987
25	65.712
30	65.712
35	52.210

This phenomena happens due to delay of the signal's arrival during long distance transmission and this effect can be overcome by rearranging the experimental setup by using amplifier. The mmw signal produced by the proposed method is checked for its robustness after transmitting it through a fiber of length 60 km. The simulation result of fiber length versus BER performance and extinction ration versus quality factor emphasizes on the quality of the mmw signal generated by the proposed method. Since optical filter is not used in the proposed method, broadband long distance data transmission can be effectively performed using the proposed method.

VI. Conclusion

The paper provides a reliable experimental setup for the generation of 12 tupling mmw using a single LiNbO3 modulator without an optical filter. The use of carrier suppression method has the advantages like high data rate and error free long distance transmission for a 120 GHz mmw signal. The detailed theoretical analysis has been carried out for the generation of mmw from a microwave range input. The simple setup of the proposed system makes it cost effective and reliable for high speed data transfer with negligible BER. The propagation loss and fading effect is also overcome by transferring the mmw through a single mode fiber over 60 km by setting the bias voltage as 10 V. The quality and efficiency of the generated mmw signal is verified by using the spectrum analyzers and the result proves the robustness of the generated mmw signal.

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